

An inconvenient routine: introduction, establishment and spread of new non-native fishes in the Paraíba do Sul River basin, state of Minas Gerais, Brazil

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Abstract

This study updates the introduction of non-native fishes *Nannostomus beckfordi*, *Aphyocharax anisitsi*, *Knodus moenkhausii*, *Moenkhausia costae*, *Ancistrus multispinis* and *Astronotus ocellatus* in the largest ornamental aquaculture center located in Paraíba do Sul River basin, state of Minas Gerais, Brazil. There is evidence that all species are established and that some are spreading to a reservoir in the region. Management actions such as awareness campaigns to educate fish farmers and the inspection of fish farms carried out by IBAMA officials are suggested to avoid new introductions and spread.

Resumo

Uma rotina inconveniente: introdução, estabelecimento e disseminação de novos peixes não-nativos na bacia do rio Paraíba do Sul, estado de Minas Gerais, Brasil. Este estudo atualiza a introdução de espécies não-nativas, *Nannostomus beckfordi*, *Aphyocharax anisitsi*, *Knodus moenkhausii*, *Moenkhausia costae*, *Ancistrus multispinis* e *Astronotus ocellatus* no maior polo de piscicultura ornamental localizado na bacia do rio Paraíba do Sul, Minas Gerais, Brasil. Há evidências de que todas as espécies estão estabelecidas e que algumas já encontram-se povoando um reservatório na região. Recomendações como conscientização dos piscicultores e fiscalização das pisciculturas pelo IBAMA são sugeridas para evitar novas introduções e disseminação.

Keywords

Aquaculture, aquarium trade, biological invasion, invasive species, spread

Palavras-chave

Aquicultura, aquários, invasão biológica, espécie invasora, disseminação

Introduction

The intentional or unintentional introduction of aquatic non-native species is increasing around the globe (Lockwood et al. 2007). It is considered one of the main environmental damages caused by humans over the past 10,000 years (Perry and Vanderklein 1996), along with global warming (Rahel and Olden 2008). The relevance of non-native species has grown in the field of conservation biology and ichthyology, since a series of recent surveys has indicated that the introduction of species, including ornamental ones, is the second major threat to native freshwater fish in the world, after the degradation of aquatic habitats (Harrison and Stiassny 2004; Magalhães 2010).

The rate of fish introduction has increased rapidly in Brazil since the late 1980s (Welcomme 1988). A new phase is in progress unleashed by greater demand for aquarium trade (Magalhães and Jacobi 2016). This trade has promoted the introduction of lebiasinids, characids and cichlids among basins, as well as the introduction of non-Neotropical groups such as cyprinids, cobitids and osphronemids (Magalhães and Jacobi 2008; Moraes et al. 2017). Among the 27 Brazilian states, Minas Gerais ranks first in fish introductions not only in Brazil but in South America, with 85 non-native species, 57 of which are ornamental species (Magalhães and Jacobi 2016).

Recording the presence of new exotic ornamental fish species is essential to mitigate the effects of its introduction and prevent its further spread (Magalhães 2010; Vitule et al. 2019). In the context of tropical systems such as Brazil and state of Minas Gerais, with 17 watersheds where native aquatic biodiversity is generally high, knowledge of non-native species introductions may help to limit the possible loss of biodiversity (Magalhães and Jacobi 2016). Thus, this paper aims to: (1) report the first record of six new non-native fish species in the Muriaé Ornamental Aquaculture Center, Paraíba do Sul River basin, state of Minas Gerais; (2) evaluate the establishment status; (3) analyze its natural spread through a conceptual model; and (4) suggest management actions to prevent new introductions and spread in the region.

The Muriaé Ornamental Aquaculture Center (Magalhães and Jacobi 2013); was founded in 1979 and is located on the drainage of Upper Muriaé River (length: 250 km, drainage area: 8,292 km²), Glória River sub-basin (length: 101 km, drainage area: 1,045 km²) in state of Minas Gerais, Paraíba do Sul River basin. The area comprises 13 cities and two villages with more than 350 fish farms and about 4,500 earthen/concrete ponds ranging from 4-m² to 70-ha water surface area (Magalhães and Jacobi 2016). Juveniles and adults were collected with sieves (0.3 mm mesh) every two months (January to December) in different years in seven headwater creeks:

Boa Vista (21°01'23"S; 42°21'45.7"W); Pinheiros (20°53'44.7"S; 42°22'03.5"W); Chato (20°57'18.5"S; 42°17'25.1"W) in 2015, Boa Sorte (21°02'15.1"S; 42°21'08.3"W) in 2015 and 2017, Varginha (20°54'33.3"S; 42°23'05.8"W) in 2017, Rochedo (21°07'19.7"S; 42°18'38.1"W) and São Luiz (20°49'10.4"S; 42°19'20.9"W) in 2018 totaling 108 samples. Twelve samples were made at the Glória reservoir (21°01'07.8"S; 42°21'37"W) in 2015/2017 and the fishing gear used to capture juveniles/adults included a cylindrical-shaped trap (0.3-mm mesh) and seines (0.5–1.0-cm mesh). All these creeks and reservoir are located in southeastern Brazil (Figure 1). The fishes were euthanized on an ice slurry, a method approved for field work by IACUC (2002), sorted by site collection, fixed in 10% formalin, and subsequently transferred to 70% alcohol. Species identification and native range was based on Axelrod et al. (2005), Buckup et al. (2007), Graça and Pavanelli (2007), Nelson et al. (2016), Ota et al. (2018), Froese and Pauly (2019), and Eschmeyer et al. (2019). Fishes were dissected to access macro and mesoscopically the reproductive stages: 2 = mature, 3 = spawned for females and spent for males (Magalhães and Jacobi 2013). Voucher specimens used in this study (Table 1), were deposited under their respective catalogue numbers in the Universidade Federal de Sergipe fish collection (CIUFS), Brazil. To assess in detail the spread of the species, the distances in km from the fish farms/creeks to the point of collection in Glória reservoir were measured using the track tool of Google Earth Pro (2019) software.

The golden pencilfish *Nannostomus beckfordi* Günther, 1872, the bloodfin tetra *Aphyocharax anisitsi* Eigenmann & Kennedy, 1903, the piaba *Knodus moenkhausii* (Eigenmann & Kennedy, 1903), the blackline tail tetra *Moenkhausia costae* (Steindacher, 1907), the bristlemouth catfish *Ancistrus multispinis* (Regan, 1912) and the oscar *Astronotus ocellatus* (Agassiz, 1831) (Figure 1 A–F), were captured during the 3-year collection period, adding up to 912 specimens. From the six species captured in the present study, *K. moenkhausii*, *M. costae*, *N. beckfordi* and *A. multispinis* were the ones with the largest presence in several sites. The occurrence of juveniles and reproductive adults (stages 2 and 3) of *N. beckfordi*, *A. anisitsi*, *K. moenkhausii*, *M. costae*, *A. multispinis* and *A. ocellatus* was confirmed in all sites suggesting probable establishment by recruitment in the region (Table 1).

According to our observations, samples and interviews with fish farmers, the natural spread of the non-native species, especially *N. beckfordi*, *K. moenkhausii*, *M. costae* and *A. multispinis* occurred in the same year via unintentional escapes of production ponds, introduction into creeks and arrival in the Glória reservoir. The original introduction point (i.e., production ponds) as a focal point surrounded by concentric circles, with each successive circle representing the amount of space (i.e., creek and Glória reservoir) across which the non-native species spreads during a finite period of time (i.e., 2015), and varied between 1 and 23 km away (Figure 2). We did not record the presence of *A. anisitsi* and *A. ocellatus* in the Boa Vista, Rochedo, Pinheiros, Varginha, São Luiz and Chato creeks because these species are not cultivated in the fish farms of these areas but according to reports of local fish farmers, these species are cultivated in other distant locations in the region and are present in creeks that also run to the Glória reservoir.

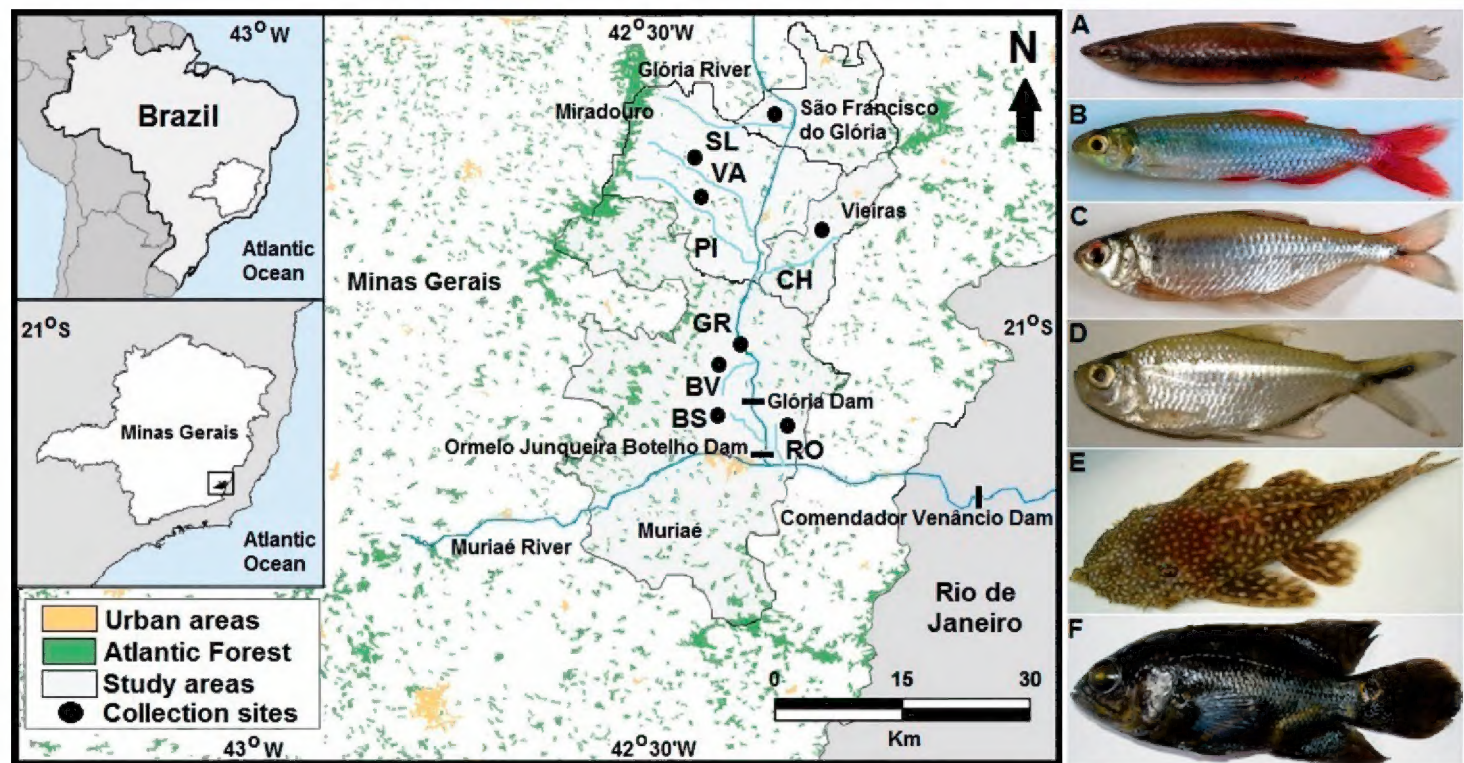


Figure 1. Map showing sampling locations in the Muriaé Ornamental Aquaculture Center. Sampling sites: BV Boa Vista, BS Boa Sorte, GR Glória reservoir, RO Rochedo, PI Pinheiros, VA Varginha, SL São Luiz, CH Chato. Main municipalities of this aquarium fish center: Muriaé, Miradouro, Vieiras, São Francisco do Glória (Modified from Santana et al. 2010). Adult non-native species: **A** *Nannostomus beckfordi* (3.7 cm total length), **B** *Aphyocharax anisitsi* (4.9 cm total length), **C** *Knodus moenkhausii* (4.2 cm total length), **D** *Moenkhausia costae* (5.5 cm total length), **E** *Ancistrus multispinis* (9.8 cm total length), **F** *Astronotus ocellatus* (19.8 cm total length).

With the exception of *N. beckfordi* that is already introduced in a region near to an ornamental aquaculture center (i.e., Maurício Dam, Pinho River sub-basin) (Magalhães and Jacobi 2008), but not in the water bodies belonging to the Muriaé and Glória rivers in the Muriaé Ornamental Aquaculture Center (Magalhães comm. pers.), it is the first record of *A. anisitsi*, *K. moenkhausii*, *M. costae*, *A. multispinis* and *A. ocellatus* for the Paraíba do Sul River basin in the state of Minas Gerais. These species' importance to the aquarium trade probably account for their spread in many Brazilian watersheds. The non-native *A. anisitsi* is found introduced in the state of Rio Grande do Sul in the municipalities of Livramento, at Ibicuí River and Uruguaiana at Guarupa River, and in state of Rio de Janeiro in the municipalities of Niterói at Itaipu Lagoon sub-basin, and Macaé at Macaé River basin. *Moenkhausia costae* is found in the Araguari (Upper Paraná River basin) and Jequitinhonha rivers in Minas Gerais and *K. moenkhausii*, *A. multispinis*, and *A. ocellatus* are found in the Paraíba do Sul River basin in the states of São Paulo and Rio de Janeiro respectively (Neto 2010; Rocha et al. 2011; Pinese 2013; Latini et al. 2016; Honório and Martins 2018). According to local fish farmers, the culture of golden pencilfish, bloodfin tetra, blackline tail tetra, bristlemouth catfish and the oscar is intended for the aquarium trade. The piaba is reared exclusively as live food (i.e., “feeder fish”) for large predatory aquarium fish such as the oscar. Thus, this is the first record of the introduction of a fish used as live food in Brazil. According

Table 1. Data of new records of non-native species captured in the Muriaé Ornamental Aquaculture Center water bodies, state of Minas Gerais, in the period from 2015, 2017 and 2018, as classified by Nelson et al. (2016). Native range from Buckup et al. (2007), Graça and Pavanelli (2007), Ota et al. (2018), Froese and Pauly (2019) and Eschmeyer et al. (2019). Fishes were dissected to access macro and mesoscopically the reproductive stages: 2 and 3. Juveniles: 1.0–1.5 cm total length for the small five species, ≤ 10.0 cm total length for *Astronotus ocellatus*.

Family/Common name/ Species	Native range	Site/Year/Voucher	N (Juvenile)	N (Adult)/Sex
Lebiasinidae	Amazon and Negro rivers, Suriname, Guyana	Glória Reservoir-2015 CIUFS 2211	63	90 (40♀, 50♂)
Golden pencilfish		Boa Vista Creek-2015 CIUFS 2213	20	23 (13♀, 10♂)
<i>Nannostomus beckfordi</i>		Boa Sorte Creek-2015 CIUFS 2212	22	34 (15♀, 19♂)
Characidae	Paraná River basin	Glória Reservoir-2017 CIUFS 2655	11	20 (15♀, 5♂)
Bloodfin tetra				
<i>Aphyocharax anisitsi</i>				
Characidae	Amazon River basin	Glória Reservoir-2015 CIUFS 2337	16	36 (20♀, 16♂)
Piaba		Boa Vista Creek-2015 CIUFS 2225	12	41 (30♀, 11♂)
<i>Knodus moenkhausii</i>		Boa Sorte Creek-2017 CIUFS 2676	18	21 (15♀, 6♂)
		São Luiz Creek-2018 CIUFS 2701	20	45 (22♀, 23♂)
		Rochedo Creek-2018 CIUFS 2702	15	53 (13♀, 40♂)
Characidae	São Francisco and Itapicuru river basins	Glória Reservoir-2015 CIUFS 2221	12	27 (15♀, 12♂)
Blackline tail tetra		Pinheiro Creek-2015 CIUFS 2647	6	21 (5♀, 16♂)
<i>Moenkhausia costae</i>		Chato Creek-2015 CIUFS 2216	9	32 (10♀, 22♂)
Loricariidae	Coastal rivers of southern Brazil	Glória Reservoir-2015 CIUFS 2233	11	35 (20♀, 15♂)
Bristlemouth catfish		Pinheiros Creek-2015 CIUFS 2219	5	15 (10♀, 5♂)
<i>Ancistrus multispinis</i>		Varginha Creek-2017 CIUFS 2663	77	59 (32♀, 27♂)
Cichlidae	Amazon, Orinoco and Paraguay river basins	Glória Reservoir-2015 CIUFS 2332	15	7 (5♀, 2♂)
Oscar		Boa Sorte Creek-2017 CIUFS 2651	9	12 (7♀, 5♂)
<i>Astronotus ocellatus</i>				

to Eskinazi-Sant'Anna et al. (2010), the use of animals as live food in the aquarium trade constitutes an additional route for species introduction in Brazilian inland waters. The present study raised the number of non-native fish species to 67 (62 of which are ornamental) for the basin, and to 90 in the state of Minas Gerais. Thus, the Paraíba do Sul River basin has more non-native species than all other watersheds in the state of Minas Gerais and the majority of Brazilian states (Magalhães and Jacobi 2016).

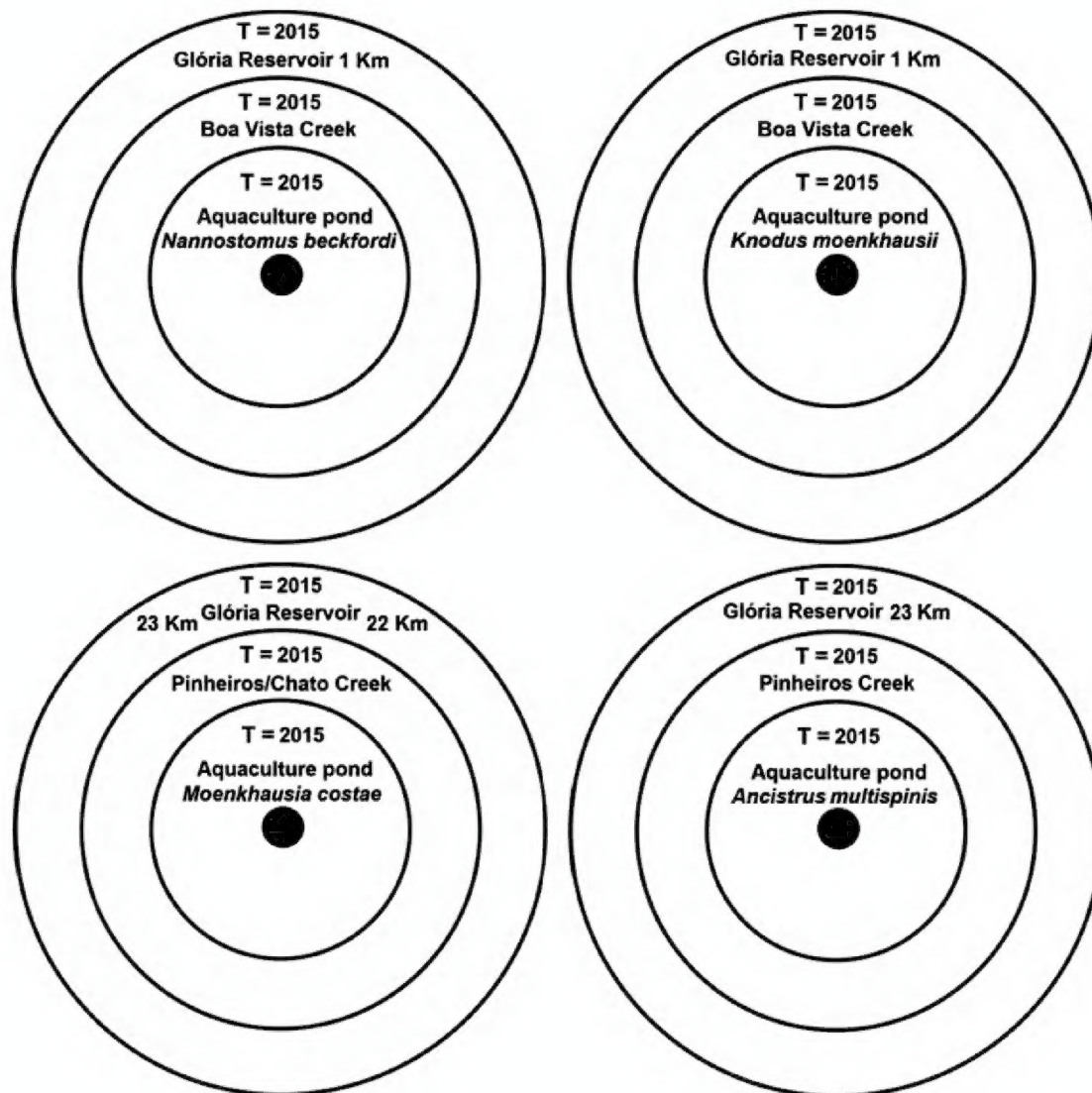


Figure 2. Conceptual model of the geographical spread of *Nannostomus beckfordi*, *Knodus moenkhausii*, *Moenkhausia costae* and *Ancistrus multispinis* in the Paraíba do Sul River basin, state of Minas Gerais, Brazil (does not include *Aphyocharax anisitsi* and *Astronotus ocellatus*). The source of release is represented by the black circle (i.e., aquaculture pond), and each circle represents the site (e.g., fish farm, creek, reservoir) and distance (i.e., km) across which *N. beckfordi*, *K. moenkhausii*, *M. costae* and *A. multispinis* spreads during a period of time (T) (i.e., 2015) (Modified from Lockwood et al. 2007).

The invasion process by a non-native species occurs in four stages: (1) Transport; (2) Introduction; (3) Establishment; (4) Spread. Within these stages, there are 11 different categories which a non-native species can attain depending on the criteria that define each category. These categories range from A through E, with each having a specific definition. An introduction is considered successful when species has recruitment of populations in the recipient environment, i.e., classification C3 or higher (Blackburn et al. 2011). In this study, it was confirmed that *N. beckfordi*, *K. moenkhausii*, *M. costae*, *A. multispinis* and *A. ocellatus* are at least in the category C3 (Establishment: individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining), and *M. costae* and *A. multispinis* belong to category D2 (Spread: self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction). In the Glória reservoir, we can assume that *A. anisitsi* and *A. ocellatus* belongs only to category D2 based on observations of local fish farmers.

All aquarium fishes that are established in drainages near or on fish farms have the potential for future spread (Courtenay et al. 1974). Accordingly, the spread process of six non-native species occurred through the escapes from fish farms located on the slopes of the mountains and the creeks acting as stepping stones after flash floods in the rainy season, since their final portions drain directly to the Glória reservoir (Magalhães and Jacobi 2008, 2013). Considering that dams are the principal human interference in the natural hydrologic regimes, facilitating biological invasions of species that also thrive in slow or non-flowing habitats such as lebiasinids, characids, loricariids and cichlids (Alves et al. 2007; Magalhães and Jacobi 2008; Vitule et al. 2019), and Glória reservoir has a dense mat of floating aquatic plants such as the eared watermoss *Salvinia auriculata*, AUBL. and the mosquito fern *Azolla microphylla* KAULF. that provide shelter and reduce predatory pressure on the individuals of the non-native species (Magalhães 2010), these introduced fishes would probably reach the category E of the process of biological invasion in this man-made site (Spread: fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites). This prediction is supported by a study conducted from January to December 2002 at three collection sites in this reservoir, which showed that the ornamental non-native common serpaete tetra *Hyphessobrycon eques* (Steindacher, 1882) originating from fish farms bordering several creeks was the most abundant species with 1,688 specimens collected, followed by the natives guaru *Poecilia vivipara* Bloch & Schneider, 1801, yellow tetra *Hyphessobrycon bifasciatus* Ellis, 1911, lambari *Astyanax janaeirensis* Eigenmann, 1908, banded knifefish *Gymnotus* sp., pearl cichlid *Geophagus brasiliensis* (Quoy & Gaimard, 1824), trahira *Hoplias malabaricus* (Bloch, 1794), dogfish *Oligosarcus hepsetus* (Cuvier, 1829) (all values n=727) (unpublished data). Similarly, the spread (i.e., category E) of *N. beckfordi*, *K. moenkhausii* and *A. ocellatus* to Ormelo Junqueira Botelho Dam, located 3 km away from the Boa Sorte Creek and *K. moenkhausii* to Comendador Venâncio Dam, distant 53 km from the Rochedo Creek, it will be a matter of time.

Preventing future introductions and spread is the most effective way of addressing invasion by non-native fishes (Lockwood et al. 2007; Magalhães and Jacobi 2013; Vitule et al. 2019). Therefore, preventive management actions along the following lines are suggested to avoid more introductions/spread: (1) awareness campaigns to educate people who work directly in ornamental fish farms and informing that releasing non-native species, even unintentionally, is an environmental crime according to the National Law on Environmental Crimes 9.605 of 1998 and the Decree 6.514 of 2008; (2) inspection of ornamental fish farms carried out by officials of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) in order to prevent escapes based on the National Law of Wildlife Protection 5.197 of 1967; and (3) if escapes persist, levying a fine performed by the IBAMA officials.

In conclusion, if these preventive actions are not followed, and coupled with the propensity of fish farmers of the Muriaé Ornamental Aquaculture Center to diversify their cultured fishes using species from different regions of Brazil and other countries (Magalhães and Jacobi 2016), new fish will be introduced, will establish and will continue to spread throughout the region.

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